OPEN-FILE REPORT 98-10

# SEISMIC HAZARD EVALUATION OF THE LOS ALAMITOS 7.5-MINUTE QUADRANGLE, LOS ANGELES AND ORANGE COUNTIES, CALIFORNIA

**1998**

**DEPARTMENT OF CONSERVATION**
***Division of Mines and Geology***

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# PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

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Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

# INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high water table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Los Alamitos 7.5-Minute Quadrangle (scale 1:24,000).

# SECTION 1
# LIQUEFACTION EVALUATION REPORT
# Liquefaction Zones in the Los Alamitos 7.5-Minute Quadrangle, Los Angeles and Orange Counties, California

**By**

**Richard B. Greenwood**

**California Department of Conservation**
**Division of Mines and Geology**

## PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997: also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Los Alamitos 7.5-minute Quadrangle (scale 1:24,000). This account is part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

## BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Loose, water-saturated granular sediments within 40 feet of the ground surface underlie localities most susceptible to liquefaction-induced damage. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Los Alamitos Quadrangle.

## SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

# PART I

## STUDY AREA LOCATION AND PHYSIOGRAPHY

The Los Alamitos Quadrangle covers an area of about 62 square miles in southern Los Angeles County and northwestern Orange County. The map area includes all or parts of the cities of Anaheim, Artesia, Bellflower, Buena Park, Cerritos, Cypress, Garden Grove, Hawaiian Gardens, Huntington Beach, Lakewood, La Mirada, La Palma, Long Beach, Los Alamitos, Seal Beach, Stanton, Westminister. Also included within the map area is unincorporated Los Angeles County and Orange County land and part of the U.S. Naval Weapons Station.

The Orange County coastal plain is bound on the north by the inferred trace of the Norwalk Fault Zone and the late Pleistocene fan deposits associated with the adjacent anticlinal hills of the Coyote Hills Uplift (Greenwood and Morton, 1990). The main body of this coastal plain is underlain by the broad, northwest-plunging synclinal Los Angeles Basin, which includes up to 4200 feet of relatively unconsolidated Pleistocene marine and non-marine sediments (Greenwood, 1980b) and up to 170 feet of unconsolidated non-marine sediments (Fuller, 1980a).

The Los Alamitos Quadrangle includes the broad southern margin of the Los Angeles Basin, which culminates abruptly with coastal hills and mesas associated with the Newport-Inglewood Uplift. This uplift of broadly warped coastal mesas, represented by Landing Hill and Alamitos Heights in the Los Alamitos Quadrangle, are composed of late Pleistocene marine terrace deposits which are covered with a veneer of older alluvium. To the southeast in the Newport Beach Quadrangle coastal mesas expose marine terrace deposits, which are underlain by late Miocene to early Pleistocene marine sediments. The coastal mesas in the Los Alamitos Quadrangle are separated by Alamitos Gap, a deeply incised by antecedent drainage of the latest Pleistocene to earliest Holocene ancestral Rio Hondo and San Gabriel River.

Access to various parts of the quadrangle is by means of Interstate Highway 405 (San Diego Freeway) and Interstate Highway 605 (San Gabriel River Freeway). The Pacific Coast Highway (State Highway 1) cuts across the southwestern corner of the map and both Interstate Highway 5 (Santa Ana Freeway) and State Highway 91 (Artesia Freeway) cut across the northeastern corner of the map. The quadrangle is also covered by a gridwork of major avenues.

## GEOLOGIC CONDITIONS

### Surface Geology

Geologic mapping of late Quaternary alluvial deposits, digitally compiled by the Southern California Areal Mapping Project (SCAMP, 1995), was used to evaluate the distribution and character of young, unconsolidated sediments exposed in the Los Alamitos Quadrangle. This geologic map relied extensively on early soil surveys (Echmann and others, 1916; Nelson and others, 1919), to which geologic nomenclature was applied. Additional detail was added from the Long Beach 1:100,000-scale digital geologic map, prepared by the California Division of Mines and Geology (Bezore and others, unpublished).

Quaternary geologic contacts received minor modifications in accordance with early edition 1:62,500-scale topographic maps (Downey, 1902) and the old regional soils maps (Echmann and others, 1916 and Nelson and others, 1919). Stratigraphic nomenclature was revised to follow the format developed by SCAMP (Morton and Kennedy, 1989). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

The mapped units fall into five basic sediment types: 1) late Pleistocene marine terrace deposits and overlying veneer of older alluvium (Qvoa/s), dense silty sands that cover Alamitos Heights and Landing Hill (Seal Beach); 2) Holocene alluvial soft sand, silt, silty sand, and clay of distal fan deposits (Qyf/a, Qyfa/s, Qyfa/c), associated with the active Rio Hondo, San Gabriel River, and Santa Ana River alluvial systems; 3) an occurrence of modern eolian deposits (Qyes); and 4) large areas of artificial fill (af), which cover extensive modern beach sands and lagoonal deposits.

Prior to the development of Alamitos Bay, extensive estuarine deposits were present at the mouth of the abandoned drainages of Rio Hondo, the Santa Ana River, and the present San Gabriel River. The organic tidal muds therein were extensively dredged and covered in many places with artificial fill (af).

**Subsurface Geology and Geotechnical Characteristics**

Information on subsurface properties was obtained from more than 465 borehole logs in the study area. Subsurface data used for this study include the database compiled for previous liquefaction studies in Los Angeles County (Tinsley and Fumal, 1985; Tinsley and others, 1985) and for previous seismic ground response studies in the Orange County area (Sprotte and others, 1980). Additional data were collected for this study from the files of the Orange County Public Health Department, Environmental Health Division, Orange County Public Works Department, Construction and Design Divisions, Municipal Water District of Orange County, Caltrans, Southern California District of the California Department of Water Resources, California Water Quality Control Board, and the California State Architect's Office. Data from previous databases and additional borehole logs were entered into the DMG GIS database. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized, but give the most commonly encountered characteristics of the units (see Table 1.1).

| Geologic Map Unit | Material Type | Consistency | Liquefaction Susceptibility |
|---|---|---|---|
| **Af, artificial fill** | Sand, silty sand | Soft to dense | High |
| **Qyf/a, Younger alluvium** | Silty sand, and sand | Soft | High |
| **Qyes, Modern Eolian Deposits** | Sand | Soft | Low to moderate |
| **Qvom/s, Marine Terrace Deposits** | Silty sand, minor gravel | Dense-very dense | Low |

**Table 1.1. General geotechnical characteristics and liquefaction susceptibility of younger Quaternary units.**

### *Older alluvium (Qvom/a, Qvom/c, Qvom/s) covering marine terrace deposits*

Older alluvium overlies, but is not differentiated from, late Pleistocene terrace deposits on Alamitos Heights and Landing Hill. Ground water is deep throughout these areas, so no extensive effort was made to collect subsurface data. They are generally described as dense to very dense sand and silty sand deposits.

### *Modern eolian deposits (Qyes)*

Modern eolian deposits are composed of very well sorted, fine- to medium-grained sand.

### *Younger alluvium (Qyf/a)*

Younger alluvium associated with the lowlands of the San Gabriel River and Santa Ana River were not subdivided into “alluvium” and “floodplain” deposits. These deposits consist of soft sand (Qyf/a), silt (Qyf/s), and clay (Qyf/c).

### *Artificial fill (af)*

Artificial fill in the Los Alamitos Quadrangle consists of undifferentiated young and old fills associated with development of the greater Alamitos Bay complex and the City of Seal Beach.

## Subsurface Stratigraphic Analysis

An analysis of the local subsurface geology reveals a dynamic interaction between the Rio Hondo, San Gabriel River, and Santa Ana River fans and the coastal mesas, whose elevation is related to deformation along the Newport-Inglewood Fault Zone. The reference time-frame of the depositional regime is controlled by the last “low stand” of sea level—approximately 20,000 years ago (McNeilan and others, 1996). During that time, local drainages became incised because of lower base levels (for example, sea level was 100’s of feet below the modern level).

Although the immediate scope of the present study focuses on geologic conditions within 50 feet of the ground surface, an appreciation of the underlying aquifers assists in establishing a temporally constrained (Holocene) stratgraphic framework for determining the nature and distribution of overlying, potentially liquefiable sediments.

The temporally constrained stratigraphic framework of the subsurface sediments defines which of these underground, potentially liquefiable sediments are of Holocene age—and, accordingly, meet the “latest Pleistocene to present” age restrictions, which are imposed by the official criteria developed by the California State Mining and Geology Board (in press).

### *Latest Pleistocene to Earliest Holocene (?) Aquifers*

The stratigraphic base of the Holocene is related to the most recent Pleistocene rise in sea level, which raised stream-base levels, that led to the deposition of fan sediments. This latest Pleistocene to earliest Holocene (?) fluvial backfilling of incised drainages controlled the initial distribution of coarse-grained sediments, locally named the Gaspur aquifer in Los Angeles County and the Bolsa and Talbert aquifers in Orange County (Mendenhall, 1905). These depositional processes have been well documented in Poland and others (1956) and Poland (1959). The depth to base, thickness, and lateral distribution of the Bolsa and Talbert aquifers were mapped by Fuller (1980b), who showed the tops to be generally less than 70 feet deep in the coastal gap areas.

### *Earliest-Holocene to Modern Sediments*

The distribution of Holocene sediments, as recorded in early editions of regional soil survey maps (Eckmann and others, 1916; Nelson and others, 1919), suggests that the Rio Hondo, San Gabriel River, and Santa Ana River have, during the recent past, moved back and forth across the Los Angeles County and Orange County coastal plains from Los Angeles Harbor to Alamitos Bay and from Alamitos Bay to Newport Bay, respectively. Historical accounts further support the conclusion that widespread sheet flooding has been the dominant depositional process associated with the Rio Hondo, the San Gabriel River, and the Santa Ana River. This went on until the construction of Prado Dam and Whittier Narrows Dam (California Department of Water Resources, 1959).

Regional cross sections were constructed using Caltrans and underground tank borehole data, which allowed the definition of at least four and as many as six regional, repetitive, upward-fining sequences of fluvial sediments, with recognizable lateral continuity in the Orange County Coastal Plain (Greenwood, 1998). The cross-sectional models became better defined as local cases of crosscutting relationships and longitudinal facies changes also became apparent. Stratigraphic units were first identified via correlations of lithology and standard penetration tests (SPT) of deep geotechnical boreholes (generally 60 to 80 feet) along U.S. Interstate Highway 5 (I-5) and 405 (I-405). These detailed geotechnical borehole logs were placed in cross sections having a horizontal scale of 1 inch=1000 feet and a vertical scale of 1inch=10 feet.

## GROUND-WATER CONDITIONS

Saturated conditions reduce the normal effective stress acting on loose, near-surface sandy deposits, thereby increasing the likelihood of liquefaction (Youd, 1973). A ground-water evaluation of alluviated areas was performed in order to determine historical shallowest ground-water levels in the Los Alamitos Quadrangle. Ground-water depth data were obtained from compiled geotechnical boreholes, environmental monitoring wells, and water-well logs. The data were then plotted onto computer-generated maps of the project area. Areas characterized by historical highest ground water or perched water with depths of less than 40 feet are considered for the purposes of liquefaction hazard zoning. The evaluation was based on first-encountered water levels encountered in geotechnical boreholes and selected water wells. The depths to first-encountered water, free of piezometric influences, were plotted and contoured onto a map showing depths to historically shallowest ground water (Plate 1.2). This map was digitized and used for the liquefaction analysis.

# PART II

## EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water-saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to evaluate liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

## LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Los Alamitos Quadrangle, peak accelerations of 0.40 g to 0.51 g resulting from an earthquake of magnitude 6.7 to 6.8 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

## LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense. Cohesive soils are generally not considered susceptible to liquefaction.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.1.

**Older alluvium (Qvom/s) covering marine terrace deposits**

Older alluvium overlies, but is not differentiated from, late Pleistocene terrace deposits. Ground water is deep throughout the areas of older alluvium, so no extensive effort was made to collect subsurface data. Older alluvium is generally described as dense to very dense sand and silty sand. Liquefaction susceptibility of the unit is low.

**Younger alluvium (Qyf/a)**

Younger alluvium associated with the lowlands of the San Gabriel and Santa Ana Rivers were not subdivided into "alluvium" and "floodplain" deposits. These deposits consist of soft sand (Qyf/a), silt (Qyf/s), and clay (Qyf/c). Where this unit is saturated, liquefaction susceptibility is high.

**Artificial fill (af)**

Artificial fills commonly overlie young alluvial or estuarine deposits. Because the artificial fills are usually too thin to affect the liquefaction hazard, and the underlying estuarine and alluvial deposits have a high liquefaction susceptibility, they are assumed to have a high susceptibility to liquefaction.

**Quantitative Liquefaction Analysis**

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses, expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Borehole logs compiled for this study include 271 that had blow counts from standard penetration tests or from tests that could be converted to SPTs. Few included all of the required information (SPTs, density, water content, percentage of silt and clay size grains) for a complete Seed

Simplified analysis. For those boreholes where SPTs were recorded, the liquefaction analysis was conducted either using data from that borehole or if the other data were lacking, extrapolated from nearby boreholes in similar materials.

## LIQUEFACTION ZONES

### Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Los Alamitos Quadrangle is summarized below.

### *Areas of Past Liquefaction*

In the Los Alamitos Quadrangle, numerous effects attributed to liquefaction were noted in the coastal areas of the City of Long Beach and in the soft sediments along the San Gabriel River near Alamitos Bay following the 1933 Long Beach earthquake. Observed damage and effects include including buckled and displaced pavement, fill settlement, surficial cracks, and "mud volcanoes" formed near the north end of Seal Beach (Barrows, 1974).

### *Areas with Existing Geotechnical Data*

The marine terrace deposits and/or Older alluvial covering, as exposed in the Los Alamitos Quadrangle (Qova/s) generally have a dense consistency, high fines content, or deep ground water and accordingly have not been included in liquefaction hazard zones. Younger alluvial deposits (Qyf/a) commonly have layers of loose silty sand or sand. Where these deposits are saturated, they are included in a liquefaction hazard zone. Younger eolian deposits (Qyes) are typically very thin and permeable and located on a slope, and therefore, unsaturated. They are not included in liquefaction hazard zones.

### *Artificial Fills (af)*

In the Los Alamitos Quadrangle artificial fill consists of artificial fill around Alamitos Bay, and the City of Seal Beach. Residential-related engineered fills are generally too thin to have an impact on liquefaction, but fills which overlie estuarine deposits are more likely to be susceptible to liquefaction. Extensive low-lying areas of artificial fill have been included in liquefaction hazard zones.

## ACKNOWLEDGMENTS

The author thanks staff from the Orange County Public Health Department, Environmental Health Division, Orange County Public Works Department, Construction and Design Divisions, Municipal Water District of Orange County, Caltrans, Southern California District of the Department of Water Resources, and the Los Angeles Regional Water Quality Control Board for their assistance in obtaining geotechnical information used in the preparation of this report. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the liquefaction zone map and this report.

## REFERENCES

Barrows, A.G., 1974, A review of the geology and earthquake history of the Newport-Inglewood structural zone, Southern California: California Division of Mines and Geology Special Report 114, 115 p., scale 1:125,000.

Bezore, S.P., Saucedo, G.J. and Greenwood, R. G., (unpublished), Geologic map of the Long Beach 100,000-scale Quadrangle.

California Department of Water Resources, 1957, The California water plan: Bulletin No. 3, 246 p.

California Department of Water Resources, 1959, Santa Ana River investigation: California Division of Water Resources Bulletin No. 15, 207 p.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Cole, J.W., 1981, Liquefaction susceptibility of south coastal Los Angeles Basin, Orange County, California: *in* Sherburne, R.W., Fuller, D.R., Cole, J.W., Greenwood, R.B., Mumm, H.A., Real, C.R., *editors*, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 81-10LA, plate IV, scale 1:48,000.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Eckmann, E.C., Strahorn, A.T., Holmes, L.C. and Guernsey, J.E., 1916, Soils map of the Anaheim area, California: United States Department of Agriculture, Bureau of Soils, in cooperation with University of California, Agricultural Experiment Station, scale 1:62,500.

Fuller, D.R., 1980a, Thickness map of Holocene age sediments: *in* Sprotte, E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., *editors*, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19LA, Map Number 3, 4 plates.

Fuller, D.R., 1980b, Talbert and Bolsa aquifers map: *in* Sprotte E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., *editors*, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19LA, Map Number 5, 4 plates.

Greenwood, R.B., 1980a, Isobath map of near-surface water: *in* Sprotte, E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., *editors*, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19, Map Number 1, 4 plates.

Greenwood, R.B., 1980b, Thickness of Quaternary age sediments: *in* Sprotte, E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., *editors*, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19, Map Number 4, 4 plates.

Greenwood, R.B., 1998, Stratigraphic section of Holocene-age sediments, Orange County Coastal Plain: Geological Society of America Annual Meeting Cordilleran Section, Abstracts with Programs, v. 30, no. 5, p. 16.

Greenwood, R.B. and Morton, D.M., 1990, Geologic map of the Santa Ana 1:100,000 Quadrangle, California: California Division of Mines and Geology Open-File Report 91-17, 3 plates.

McNeilan, T.W., Rockwell, T.K. and Resnick, G.S., 1996, Style and rate of Holocene slip, Palos Verdes Fault, southern California: Journal of Geophysical Research, v. 101, no. B4, p. 8,317-8,334.

Mendenhall, W.C., 1905, Development of underground waters in the western coastal plain region of southern California: U.S. Geological Survey Water-Supply Paper 139, 105 p.

Morton, D.M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series: The Santa Ana Quadrangle, The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

Nelson, J.W., Zinn, C.J., Strahorn, A.T., Watson, E. B. and Dunn, J.E., 1919, Soil survey of the Los Angeles area, California: U.S. Department of Agriculture, Bureau of Soils, 78 p., map scale 1:62,500.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, affected by the 17 January 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Poland, J.E., Piper, A.M. and others, 1956, Ground-water geology of the coastal zone Long Beach-Santa Ana area, California: U.S. Geological Survey Water Supply Paper 1109, 162 p., Plate 2, southern half, map scale 1:31,680.

Poland, J.F., 1959, Hydrology of the Long Beach-Santa Ana area, California: U.S. Geological Survey Water Supply Paper 1471, 257 p.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Sprotte, E.C., Fuller, D.R., Greenwood, R.B., Mumm, H.A., Real, C.R. and Sherburne, R.W., 1980, Classification and mapping of Quaternary sedimentary deposits for purposes of seismic zonation, south coastal Los Angeles Basin, Orange County, California: California Division of Mines and Geology Open-File Report 80-19, Map Number 4, 4 plates.

Southern California Areal Mapping Project, unpublished, Digital geologic map of the Los Alamitos 7.5-minute Quadrangle, scale 1:24,000.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles Region—An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I. *editor*, Evaluating earthquake hazards in the Los Angeles region—An earth science perspective: U.S. Geological Survey Professional Paper 1360, p 263-316.

USGS (U.S. Geological Survey), 1902 edition, Topographic map of the Downey 15-minute Quadrangle, scale 1:62,500, contour interval 25 feet.

Youd, T.L. 1973, Liquefaction, flow, and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M. 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

# SECTION 2
# EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

## NO LANDSLIDE HAZARDS ZONED

Within the Los Alamitos Quadrangle, no areas have been designated as "zones of required investigation for earthquake-induced landslides." However, the potential for landslides may exist locally, particularly along streambanks, margins of drainage channels, and similar settings where steep banks or slopes occur. Within the liquefaction zones, some of these settings may be susceptible to lateral-spreading (a condition wherein low-angle landsliding is associated with liquefaction). Also, landslide hazards can be created during excavation and grading unless appropriate techniques are used.

# SECTION 3
# GROUND SHAKING EVALUATION REPORT

## Potential Ground Shaking in the Los Alamitos 7.5-Minute Quadrangle, Los Angeles and Orange Counties, California

**By**

**Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real and Michael S. Reichle**

**California Department of Conservation**
**Division of Mines and Geology**

### PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple

Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Section 1, addressing liquefaction hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

## EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

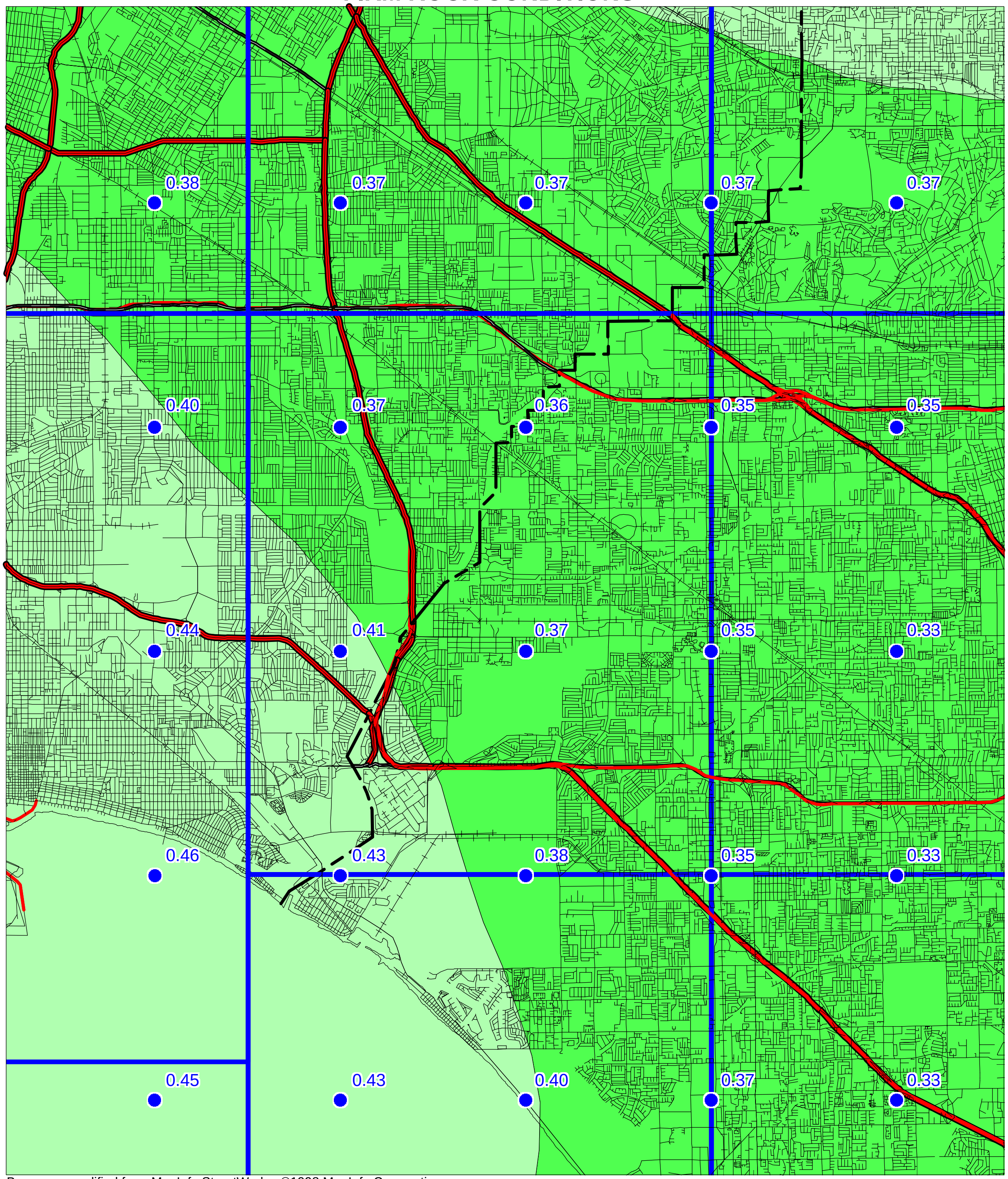
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

# LOS ALAMITOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

*10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)*

1998

**FIRM ROCK CONDITIONS**






0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

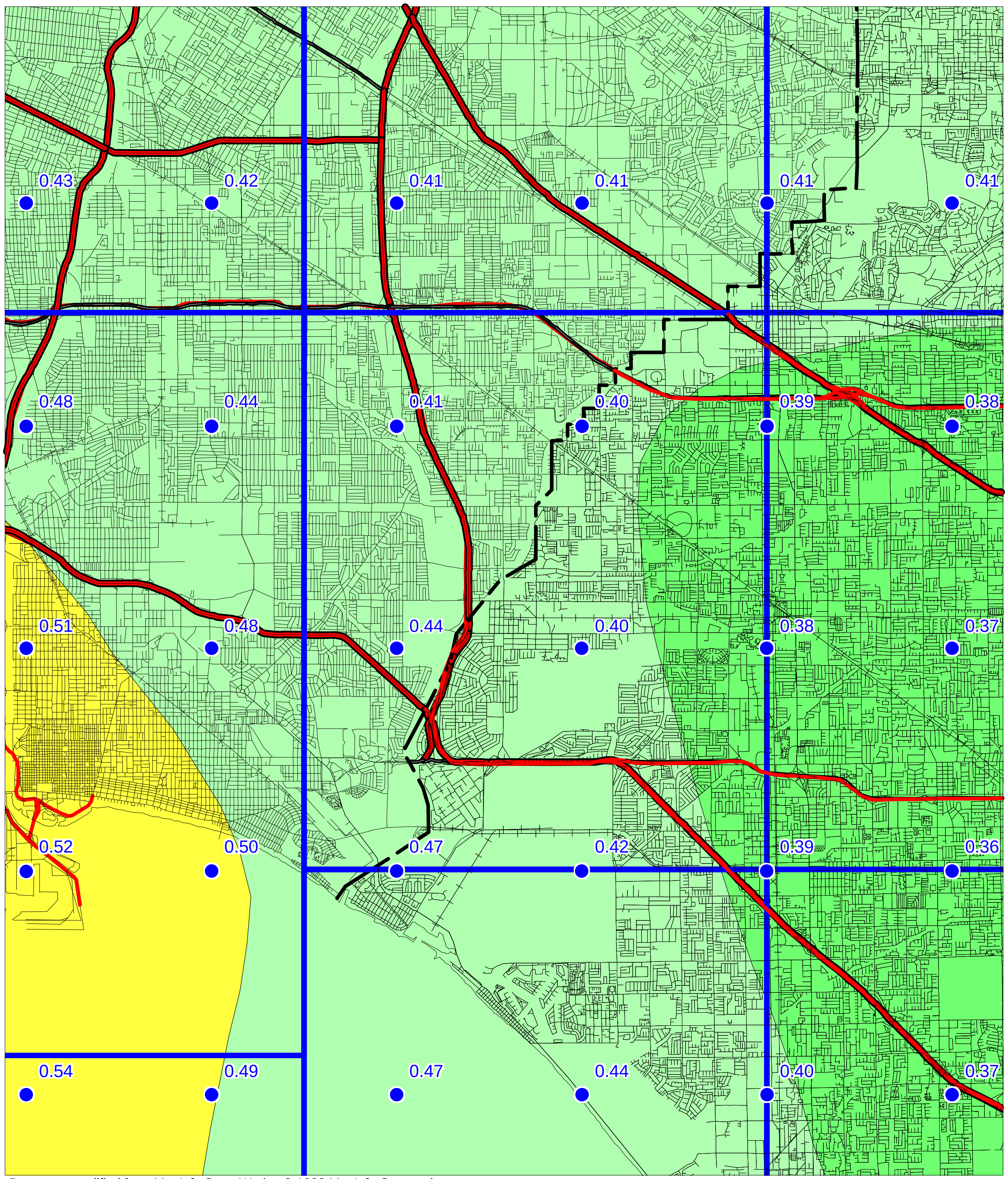
Figure 3.1

# LOS ALAMITOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

*10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)*

1998

**SOFT ROCK CONDITIONS**






0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

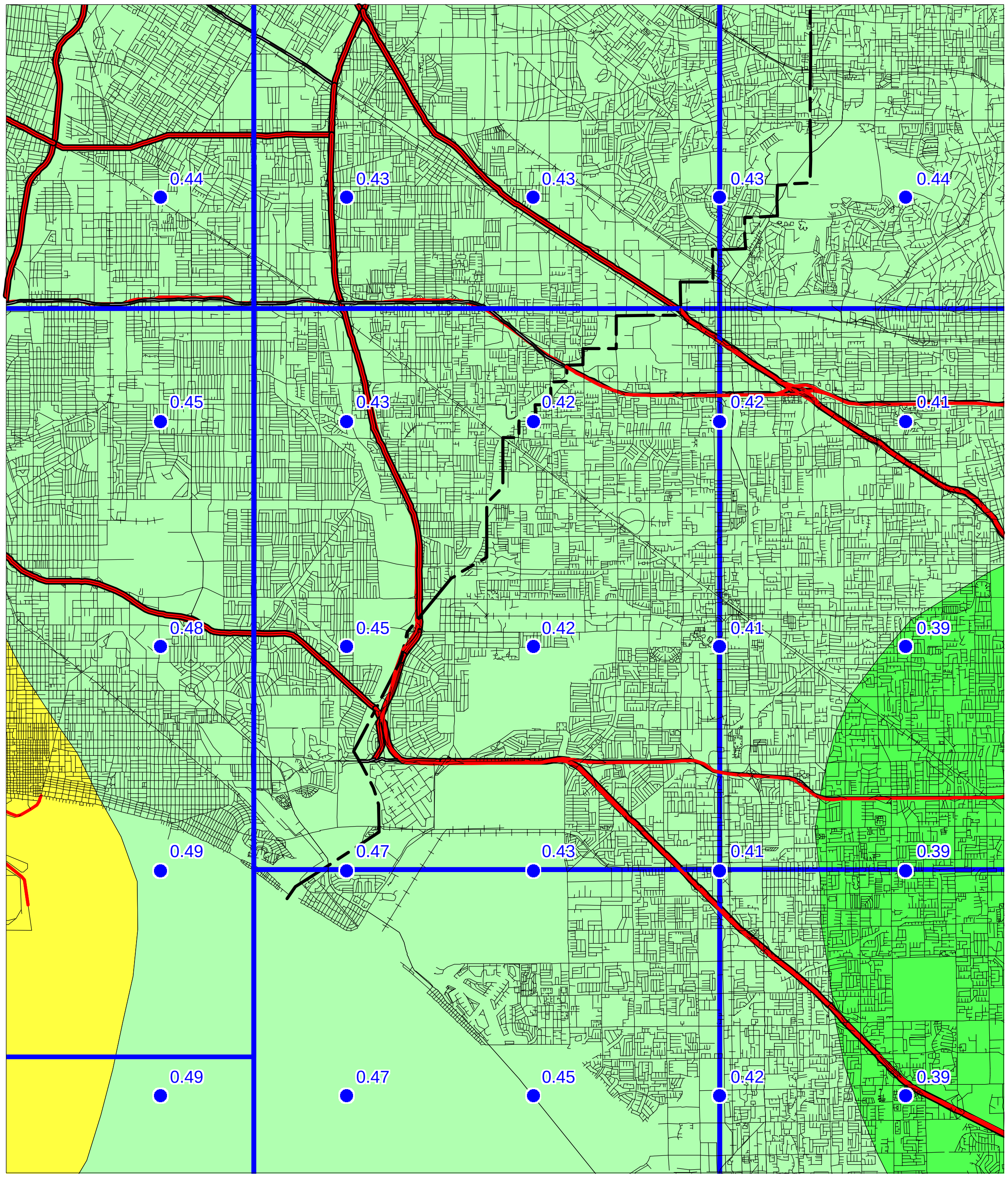
Figure 3.2

# LOS ALAMITOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

*10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)*

1998

**ALLUVIUM CONDITIONS**




Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5

Kilometers

Department of Conservation
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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

## APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

## USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

LOS ALAMITOS 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

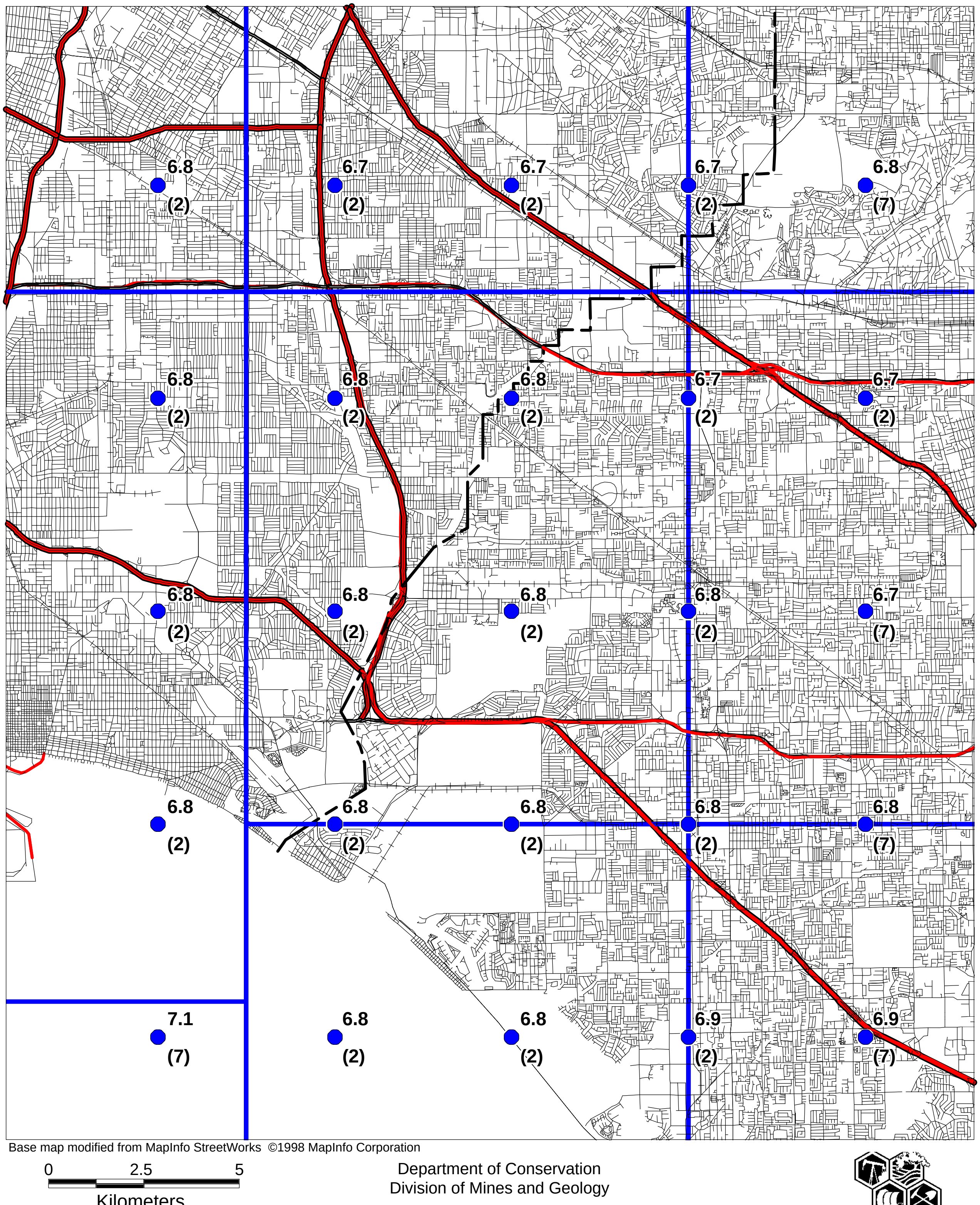
*10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION*

1998

**PREDOMINANT EARTHQUAKE**

**Magnitude (Mw)**

**(Distance (km))**




Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

Department of Conservation
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Figure 3.4

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

## REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, Map No. 8, scale 1:750,000.

Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 66 p.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.

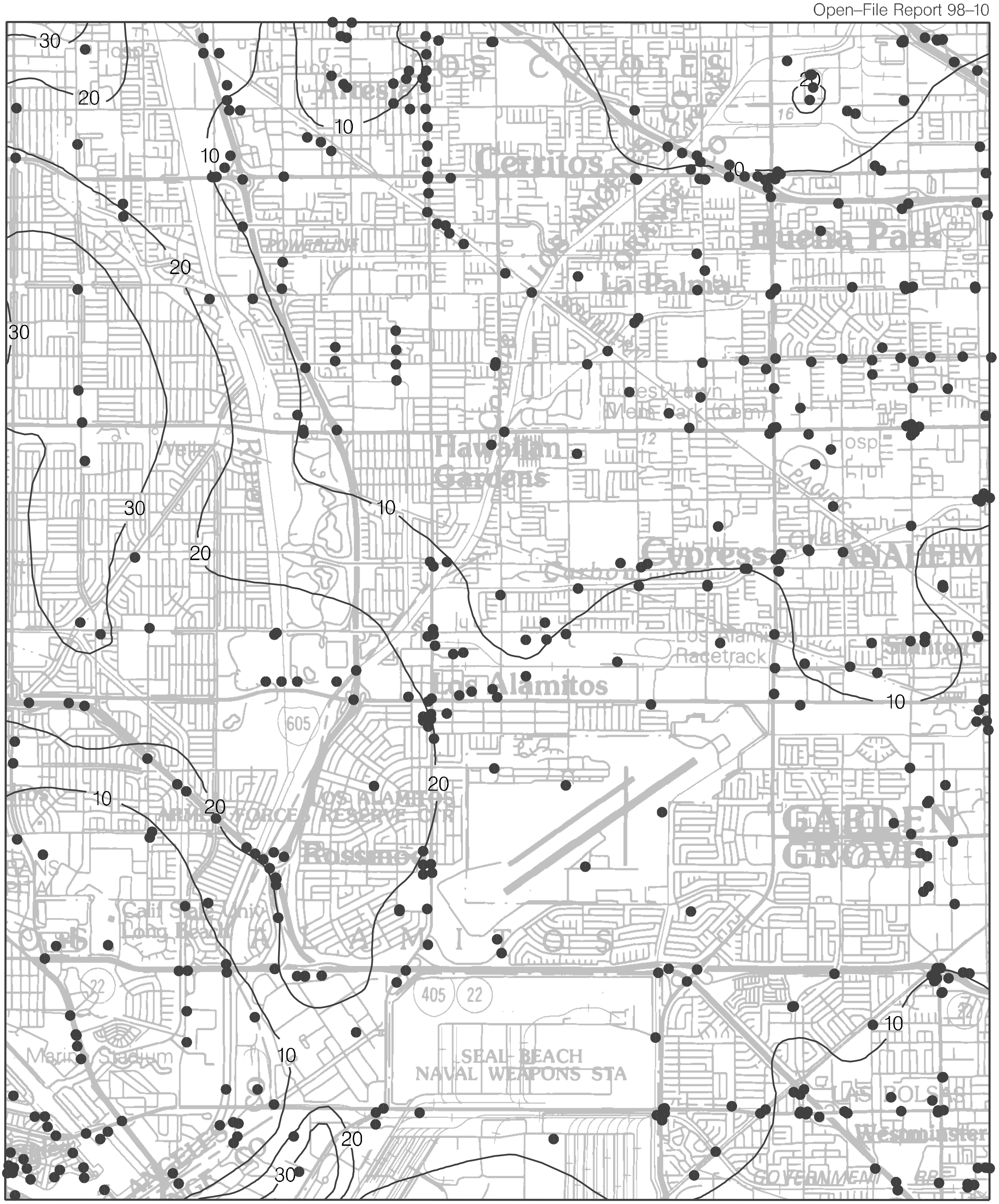

Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Los Alamitos Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

ONE MILE

SCALE




Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Los Alamitos Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE